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MODELING ARMY MANEUVER AND TRAINING BASE REALIGNMENT AND CLOSURE

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Title XXIX of United States Public Law 101-510, the Defense Base Closure and Realignment Act of 1990, provides procedures for closure or realignment of major department of Defense installations. This law and subsequent legislative amendments require installations slated for closure to have been impartially evaluated primarily with regard to military value and cost. This paper presents an elastic bi-criterion mixed integer programming model with military value and cost objectives developed to assist the Army with closure and realignment recommendations for maneuver and training bases. The model has assisted with Army stationing decisions and is expected to help the Army develop its 1995 recommendations.

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Modeling Army Maneuver and Training Base Realignment and Closure

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Abstract

Title XXIX of United States Public Law 101-510, the Defense Base Closure and Realignment Act of 1990, provides procedures for closure or realignment of major Department of Defense installations. This law and subsequent legislative admendments require installations slated for closure to have been impartially evaluated primarily with regard to military value and cost. This paper presents an elastic bi-criterion mixed integer programming model with military value and cost objectives developed to assist the Army with closure and realignment recommendations for maneuver and training bases. The model has assisted with Army stationing decisions and is expected to help the Army develop its 1995 recommendations.

The United States (US) Army is in a period of significant downsizing. The expected 1995 active force level of about 540,000 represents a reduction of 23% from 1989 and the lowest level since 1939; civilians employed in military functions, having been 403,000, will drop below 295,000 by 1995 (Department of Defense [1993]). The reduced personnel levels require unit realignment and base closure for more efficient operations.

Base closure decisions carry political implications and consequently any closure affecting 300 or more civilian employees or any realignment eliminating more than 1,000 or 50% of the base's civilian employees must follow a legislated process, Title XXIX of Public Law 101-510 (the National Defense Authorization Act for Fiscal Year 1991) as amended. This act established an

independent Defense Base Closure and Realignment Commission and set in motion a base closure and realignment (BRAC) decision making process that was executed in 1991 and 1993 and will happen again in 1995. The Commission reviews Secretary of Defense recommendations for realignment and closure within the US. The President must accept or reject the commission's recommendations in its entirety. The President's decision becomes final unless Congress votes within 45 days to overturn it. The commission's 1991 and 1993 recommendations were accepted by Presidents Bush and Clinton, respectively, and neither was overturned (Defense Base Closure and Realignment Commission [1991] and [1993]).

The US Army's actions between 1988 and 1993 have closed or downsized over 30% of its installations within the US (Department of Defense [1993]). Many of these actions corrected inefficiencies caused by a lack of significant base realignment for more than a decade prior to 1988; Congressional actions were primarily responsible for the lack of realignment during this period (Defense Secretary's Commission on Base Realignment and Closure [1988]). The need still exists, in light of reducing budgets, to continue closing and realigning bases. The 1995 BRAC submission provides perhaps the last opportunity to make intelligent restructuring decisions for the foreseeable future.

We develop and solve an elastic mixed integer program, referred to as OSUB (Optimally Stationing Units to Bases), to aid the Army with its 1995 base realignment and closure decisions for maneuver and training bases. (The methodology can be applied to any other type of military bases after determining an appropriate measure of military value. See Tarantino [1992] for an application to Army Materiel Command installations.) OSUB has evolved since its inception in 1991 (Singleton [1991]) to supplement existing Army analytical tools (Department of Army [1991] and Department of Defense [1993]) which include: D-PADS from Apian Software [1993] (commercially available software that linearly weights and combines attributes) and COBRA from R&K Engineering [1993] (software developed by government contract to calculate a pay-back period associated with any closure or

realignment action(s)). These methods were used to determine military value and cost in the Army's 1991 and 1993 BRAC recommendations which were accepted by Army leadership, the Secretary of Defense, The BRAC Commission, The Government Accounting Office, Congress, and the President. With a track record like that, these methods (whether or not they represent the best approach) are certain to remain part of the Army's 1995 process. OSUB supplements these tools by allowing rapid generation and evaluation of various BRAC options. OSUB was available for 1993 BRAC decision making and was used to assist with a stationing study (Department of the Army [1993]); the Army did not consider any BRAC actions for maneuver and training installations in 1993.

OSUB captures a wide range of detail necessary to appropriately model maneuver and training installations while relying on data that is readily available through standard Army data bases. OSUB is a capacitated facility location problem commonly found in the Operations Research literature significantly modified for application to maneuver and training BRAC. A number of excellent surveys exist for location problems (see for example, Brandeau and Chiu [1989], Current, Min, and Schilling [1990], Francis, McGinnis, and White [1983], Krarup and Pruzan [1983]). These surveys highlight location problems as a rich area of research where simple variations or new application create unique and challenging research. OSUB addresses many factors not previously expressed in any model found in the literature.

The authors are aware of only one other optimization model developed for application to base closure (Department of the Navy [1993]). The Navy used a capacitated facility location model to help develop its 1993 BRAC recommendations. The objective of their model is to minimize excess capacity subject to constraints on a single measure of capacity and an average level of military value. OSUB, as shown in the next sections, addresses a wider range of BRAC concerns.

The following sections present: 1) description of maneuver and training installations, 2) the elastic mixed integer programming formulation, 3) an

Figure 1: *Army Maneuver and training bases within the United States. Maneuver bases are shown with a "M", major training areas with a "T", and branch schools with a "S".*

OSUB application, 4) a large-scale example, and 5) conclusions.

1 Maneuver and Training Bases

Over 80% of all active duty Army soldiers receive permanent assignment to US Army maneuver and training bases located within the US. Maneuver bases (see Figure 1) primarily house, train and deploy major active component force units. Training installations divide into major training areas and branch schools. Major training areas supply land for large unit training exercises. Units are assigned, for periodic training, to these bases on a temporary basis. Branch Schools provide specialized training for anybody from new recruits to the Army leadership. A few statistics (shown in Table 1) highlight the size and infrastructure available at each of these bases.

Table 1 demonstrates that maneuver bases, major training bases, and branch schools cannot be viewed as mutually exclusive categories. While maneuver bases tend to have the greatest acreage, facilities, and housing to

Base	Total Acres	Facilities million sq. ft.	Family Housing	Bachelor Officer Housing	Bachelor Enlisted Housing
A.P. Hill, VA	76,000	1,083	0	32	266
Benning, GA	182,000	20,732	4,082	1,866	6,123
Bliss, TX	1,120,000	17,619	3,577	662	6,445
Bragg, NC	149,000	24,607	4,875	716	13,899
Campbell, KY	105,000	17,538	4,153	126	7,085
Carson, CO	373,000	11,003	1,826	183	5,938
Chafee, AR	72,000	4,780	0	33	0
Dix, NJ	31,000	9,405	2,116	322	3,102
Drum, NY	107,000	11,911	2,272	6	4,484
Eustis/Story, VA	10,000	6,698	1,320	347	2,655
Gordon, GA	56,000	9,759	877	459	8,270
Greeley, AK	677,000	1,666	337	71	209
Hood, TX	217,000	25,256	5,256	621	17,328
Huachuca, AZ	73,000	8,074	1,953	304	1,802
Hunter Liggett, CA	165,000	782	32	50	1,208
Indiantown Gap, PA	18,000	4,338	5	60	150
Irwin, CA	636,000	5,893	1,636	169	1,508
Jackson, SC	52,000	10,727	1,271	176	2,354
Knox, KY	109,000	18,441	4,366	622	4,058
Lee, VA	6,000	7,279	1,459	584	3,664
Leonard Wood, MO	63,000	11,944	2,912	687	1,998
Lewis, WA	348,000	23,731	3,508	89	7,216
McClellan, AL	46,000	6,664	571	476	3,718
McCoy, WI	60,000	6,360	16	0	28
Pickett, VA	45,000	3,103	7	0	48
Polk, LA	198,000	16,831	4,007	210	5,380
Richardson, AK	62,000	7,695	1,757	199	1,738
Riley, KS	101,000	14,105	3,136	162	5,938
Rucker, AL	64,000	8,057	1,515	772	2,526
Sam Houston, TX	31,000	10,975	1,165	654	5,408
Schofield Barracks, HI	174,000	12,310	3,704	36	6,174
Sill, OK	94,000	14,298	1,415	829	5,804
Stewart, GA	284,000	10,841	2,672	100	4,824
Wainwright, AK	656,000	7,711	1,633	232	2,980

Table 1: Army Maneuver and training bases represent significant investments in land and infrastructure.

support permanently stationed units, Fort Irwin (a Major Training Area) and Fort Bliss (a Branch School) have the acres to support permanently stationed units. Our evaluation of military value captures the characteristics which are common to all three base categories. It must be emphasized that many of the installations, especially the branch schools, perform unique roles with features that require evaluation on an individual basis.

Understanding the military value of Army installations requires knowledge of Army training. The US Army's primary purpose is to defend the country and it conducts rigorous training exercises which develop essential combat skills. Most of these training exercises require land in which to maneuver and our modeling of military value accounts for this requirement. The number of both contiguous and total maneuver acres required for training major units assigned to maneuver and training installations (see Table 2) is found in Training Circular (TC) 25-1 (Department of the Army [undated]). The contiguous requirement specifies the greatest size needed for any single exercise. The total requirement provides the estimated acres needed to conduct all yearly training without competition from other units. Typically these estimated figures are for ideal training and some reduction is usually necessary to satisfy training requirements for co-located units. (Gillman's [1993] study of maneuver acre requirements for units stationed at Fort Hood found that only 84% of required training can be accomplished. He also found that to accomplish all required training, land requirements for some units would have to be reduced by as much as 60%.) We model total and contiguous maneuver acre requirements as elastic constraints in OSUB and minimize the deviation between the ideal as reported in TC25-1 and what the base can provide.

Another essential ingredient for training units is ranges (*e.g.* rifle, machine gun, tank). Both base range availability and unit range requirements are available from Army sources (HQRPLANS Richardson and Kirme Engineering [1993]). Unit estimates are for ideal training without competition from other units. Again, we model range requirements as elastic constraints

Unit	Current Station	Total Personnel	Acres Needed	Unit	Current Station	Total Personnel	Acres Needed
Tenant/Garrison	A P. HILL	369	0	Armor School	KNOX	4,915	18,000
Infantry Center/School	BENNING	12,960	18,000	USATC	Knox	5,424	0
3rd Brigade of 24 ID	Benning	4,249	55,000	194th Armor BDE	Knox	2,403	55,000
36 Engineering Group	Benning	1,613	55,000	USAREC	Knox	1,410	0
75th Ranger Regiment	Benning	731	43,000	Tenant/Garrison	Knox	7,270	0
School of the Americas	Benning	1,263	0	Quartermaster School	LEE	5,511	14,000
Tenant/Garrison	Benning	8,306	0	Logistics Center	Lee	903	0,000
ADA School	BLISS	6,346	14,000	ALMC	Lee	926	0
11th ADA Brigade	Bliss	698	14,000	QM Group	Lee	706	43,000
3rd ACR	Bliss	4,553	55,000	Tenant/Garrison	Lee	4,867	0
Beaumont Medical Ctr	Bliss	2,204	0	Engineer Ctr and School	LEONARD WOOD	3,987	18,000
Tenant/Garrison	Bliss	5,361	0	USATC EN	Leonard Wood	10,232	0
HQ 18th ABN Corp	BRAGG	1,499	43,000	Tenant/Garrison	Leonard Wood	4,288	0
18th AVN BDE	Bragg	2,081	43,000	HQ 1st Corps	LEWIS	326	55,000
20th EN BDE	Bragg	2,063	43,000	1st Corps AVN BDE	Lewis	223	43,000
18th Arty BDE	Bragg	2,198	43,000	7th ENGR BDE	Lewis	895	55,000
16th MP BDE	Bragg	740	14,000	62nd Medical Group	Lewis	806	55,000
35th Signal Brigade	Bragg	3,278	14,000	35th ADA BDE	Lewis	1,070	55,000
525th MI BDE	Bragg	803	14,000	1st Corps FA BDE	Lewis	700	55,000
1st COSCOM	Bragg	6,269	43,000	201st MI BDE	Lewis	606	18,000
USASOC	Bragg	4,396	43,000	593rd Support Group	Lewis	4,278	55,000
JFK Warfare Ctr & School	Bragg	3,395	14,000	Manhiem BDE	Lewis	4,249	55,000
82nd Airborne Division	Bragg	13,096	129,000	1st Special Forces Group	Lewis	1,573	43,000
Tenant/Garrison	Bragg	8,881	0	Madigan Army Medical Ctr	Lewis	2,804	0
101st Air Assult Division	CAMPBELL	16,188	129,000	Tenant/Garrison	Lewis	4,449	0
5TH Special Forces Group	Campbell	2,517	43,000	Chemical School	MCCLELLAN	950	14,000
Tenant/Garrison	Campbell	4,455	0	MP School	McClellan	1,282	14,000
4th Infantry Division	CARSON	12,994	164,000	USATC	McClellan	2,888	0
43rd Support Group	Carson	1,872	55,000	Tenant/Garrison	McClellan	2,597	0
Tenant/Garrison	Carson	4,269	0	ARRTC	MCCOY	167	0
Tenant/Garrison	CHAFEE	939	0	Tenant/Garrison	McCoy	2,277	0
Tenant/Garrison	DIX	4,139	0	Tenant/Garrison	PICKET	506	0
10th Infantry Division	DRUM	8,907	129,000	FA BDE	POLK	698	55,000
Tenant/Garrison	Drum	3,123	0	ADA BDE	Polk	1,136	55,000
Trans and Aviation School	EUSTIS/STORY	1,581	14,000	Joint Readiness Training Ctr	Polk	1,024	43,000
Aviation Logistics School	Eustis/Story	2,186	0	2nd ACR	Polk	3,817	43,000
Transportation Group	Eustis/Story	4,294	43,000	Tenant/Garrison	Polk	5,701	0
Tenant/Garrison	Eustis/Story	3,648	0	6th Infantry BDE	RICHARDSON	2,715	129,000
Signal Center and School	GORDON	9,842	14,000	Signal BDE	Richardson	217	14,000
Eisenhower Medical Center	Gordon	2,138	0	Tenant/Garrison	Richardson	1,974	0
Tenant/Garrison	Gordon	2,098	0	1st Infantry Division	RILEY	12,386	164,000
Northern Warfare School	GREELEY	17	14,000	937 EN Group	Riley	1,725	55,000
Tenant/Garrison	Greeley	747	0	Tenant/Garrison	Riley	3,982	0
HQ 3rd Corps	HOOD	992	55,000	Avialtion Center and School	RUCKER	6,916	14,000
6th CAV BDE	Hood	1,911	43,000	Safety Center	Rucker	168	0
3rd Corps ADA BDE	Hood	1,059	55,000	School of Aviation MED	Rucker	60	0
504th BDE	Hood	846	14,000	Tenant/Garrison	Rucker	5,690	0
89th MP BDE	Hood	767	14,000	5th US Army	SAM HOUSTON	378	0
3rd Corps Signal BDE	Hood	1,761	14,000	Academy of Health Sciences	Sam Houston	7,288	0
3rd COSCOM	Hood	5,541	55,000	Brooke Army Medical Center	Sam Houston	3,028	0
2nd Armored Division	Hood	11,872	164,000	HQ Health Services Command	Sam Houston	1,687	0
1st Cav Division	Hood	16,390	164,000	Tenant/Garrison	Sam Houston	5,613	0
Tenant/Garrison	Hood	6,350	0	25th Infantry Division	SCHOFIELD	11,003	129,000
Intel Ctr and School	HUACHUCA	4,793	14,000	45th Support Group	Schofield	2,018	55,000
11th Signal BDE	Huachuca	2,112	55,000	Tenant/Garrison	Schofield	2,111	0
USAISC	Huachuca	969	0	Field Artillery School	SILL	4,580	18,000
Tenant/Garrison	Huachuca	4,746	0	USATC	Sill	4,552	0
Tenant/Garrison	HUNTER	986	0	3rd Corps ARTY	Sill	6,863	55,000
Tenant/Garrison	INDIANTOWN	1,298	0	Tenant/Garrison	Sill	6,366	0
National Training Ctr	IRWIN	729	164,000	24th Infantry Division	STEWART	12,023	164,000
177th Armor BDE	Irwin	2,283	55,000	Tenant/Garrison	Stewart	5,657	0
Tenant/Garrison	Irwin	3,331	0	2nd BDE of the 6th ID	WAINWRIGHT	4,024	43,000
USATC	JACKSON	13,869	0	Tenant/Garrison	Wainwright	2,025	0
Tenant/Garrison	Jackson	3,823	0				

Table 2: Major Army units stationed on maneuver and training bases. These units and levels should only be considered representative since units are constantly changing in today's downsizing environment. Acres needed are total ideal requirements per year without competition from other units.

and minimize the deviation between ideal and actual.

Deviations in maneuver acre requirements and ranges are weighted and linearly combined with the following ratings obtained from the Army's military value assessment: reserve component support (indicates reserve unit training support provided), information mission area (indicates degree of state-of-the-art communication facilities available), health care index (health care cost per eligible beneficiary), and environmental factors (impact of environment on mission activity). These additional factors are included as a fixed contribution to military value.

The definition of maneuver bases includes the capability to deploy units. This is especially demanding for contingency units which primarily deploy by air. Such units require an airstrip capable of allowing a fully loaded C5 airplane to take-off. Due to the cost and difficulty of airstrip construction, OSUB restricts contingency units to locations where this capability already exists.

The Army guarantees housing in accordance with rank and marital status for every soldier. This commitment is met either through housing on base or accommodations off-base for which soldiers are reimbursed basic allowance for quarters (BAQ), determined by rank, and a variable housing allowance (VHA), determined by location. OSUB includes elastic housing constraints for each category of housing. OSUB houses soldiers at a base until the housing limit is exceeded. The remaining soldiers are housed off-base as long as the estimated capacity of housing in the community is not exceeded. The cost to maintain housing units on each base as well as BAQ and VHA costs for personnel not housed on base are included in the OSUB cost objective function.

In addition to housing costs, the cost objective includes the following yearly estimated costs for each open base: repair and preventive maintenance allowance (RPMA), utility, and civilian personnel. RPMA and housing maintenance, for the most part, do not vary with personnel levels. Other fixed costs include civilian salaries for base operations. Utility costs are per

person and base specific.

OSUB uses five facility categories: operation/administrative, aviation maintenance, vehicle maintenance, supply and storage, community facilities, and training/instructor. HQRPLANS [1993] provides each unit's requirement for each facility category and permanent and temporary facility availability at each installation. If the units stationed at an installation require more of any category of facility than permanently available, construction costs are incurred. The construction cost varies according to category of facility and location. Temporary structures within the appropriate category are renovated at 75% of new construction cost before any new construction is undertaken.

Construction cost is a one-time expense associated with BRAC that must be limited and a constraint is added for this purpose. Moving units is a considerable cost which must be accounted for and limited. The US Army's BRAC actions between 1988 and 1993 required moving households and business on a scale equivalent to moving the entire city of Chattanooga, Tennessee. Realignment costs we consider are consistent with factors found in COBRA [1993] and provide detailed estimated personnel and equipment moving costs based on distance and region of the country. OSUB requires all units at closing bases except tenant and garrison units to move.

2 Base Realignment and Closure Model

OSUB, as the name states, optimally stations all units to all bases. The model takes unit and base input and determines the optimal location for all units over all bases or the subset under consideration. The objective guiding the assignment of units to bases is to maximize military value, minimize annual cost of operation, or to optimize some combination of these two objective functions. The explicit consideration of two objectives allows a cost versus military value tradeoff to be determined. The model can also quickly

analyze alternate force stationings.

We present the model after the introduction of appropriate notation.

- Indices:
  - i units (see Table 2),
  - j, j' bases (see Figures 1),
  - k resources (includes: total maneuver acres, contiguous maneuver acres (ca), enlisted family housing, officer family housing, enlisted bachelor housing, officer family housing, operation/administrative facilities, aviation maintenance facilities, vehicle maintenance facilities, supply and storage facilities, community facilities, training/instructor facilities, rifle ranges, machine gun ranges, and tank ranges).
- Data:
  - S_j set of units that are currently stationed at base j,
  - $futil1_j$ fixed utility of base j.
  - $fcost2_j$ fixed cost associated with keeping base j open,
  - $vutil_{ij}$ the difference in variable utility when unit i moves to base j (a positive difference indicates a desirable change),
  - $vcost_{ij}$ the difference in variable cost when unit i moves to base j (a positive difference indicates a higher cost),
  - pen_{jk} penalty per unit of deviation from resource k at base j (any deviation not associated with the military value objective (*e.g.*, housing and facilities) has a penalty of zero),
  - co_{jk} operating cost associated with deviating from resource k at base j (any deviation not associated with the cost objective (*e.g.*, maneuver acres, facilities, and ranges) has an operating cost of zero),

* cc_{jk} construction cost associated with deviating from resource k at base j (any deviation not associated with the construction cost (*e.g.*, maneuver acres, housing, and ranges) has a construction cost of zero),
* cap_{jk} capacity of resource k at base j (current stationed unit use is subtracted from the capacity for all $k \neq ca$),
* r_{ik} resource k utilization by unit i,
* cm_{ij} cost to move unit i to base j,
* $maxm$ the maximum movement cost,
* $maxc$ the maximum one-time realignment cost.

- Binary Variables:
  * $y_j = 1$ if base j is closed and 0 if it remains open.
  * $x_{ij} = 1$ if unit i moves to base j and 0 otherwise.
- Continuous Variables:
  * e_{jk} deviation from resource capacity k at base j.
- Formulation: (It is assumed that summations are taken only over combinations of units and bases corresponding to eligible assignments.)

$$\text{maximize } Z_1 = \sum_j futil_j(1 - y_j) + \sum_i \sum_j vutil_{ij} x_{ij} - \sum_j \sum_k pen_{jk} e_{jk} \quad (1)$$

$$\text{minimize } Z_2 = \sum_j fcost_j(1 - y_j) + \sum_i \sum_j vcost_{ij} x_{ij} + \sum_j \sum_k co_{jk} e_{jk} \quad (2)$$

subject to the constraints :

$$\sum_{j' \neq j} x_{ij'} \leq 1 \quad \forall j, i \in S_j \quad (3)$$

$$x_{ij} \leq (1 - y_j) \quad \forall j, i \notin S_j \quad (4)$$

$$\sum_{j' \neq j} x_{ij'} \geq y_j \quad \forall j, i \in S_j \tag{5}$$

$$\sum_{i \notin S_j} r_{ik} x_{ij} - \sum_{i \in S_j} \sum_{j' \neq j} r_{ik} x_{ij'} \leq cap_{jk} + e_{jk} \quad \forall j, k \neq ca \tag{6}$$

$$r_{ik} x_{ij} \leq cap_{jk} + e_{jk} \quad \forall j, i \in S_j, k = ca \tag{7}$$

$$\sum_i \sum_j cm_{ij} x_{ij} \leq maxm \tag{8}$$

$$\sum_j \sum_k cc_{jk} e_{jk} \leq maxc \tag{9}$$

$$e_{jk} \geq 0 \quad \forall j, k \tag{10}$$

The first objective, (1), provides a comparative measure of the military value for units assigned to bases. Objective (2) is the cost of unit stationing.

Constraint (3) ensures a unit moves at most once. Constraints (4) and (5) ensure that a bases closes only if new units are not stationed there and all currently stationed units move away. Constraint (6) measures deviations in housing, total maneuver acres, facilities, and ranges. Constraint (7) measures deviation in contiguous maneuver acres. Constraint (8) limits the maximum unit movement cost. Constraint (9) states that the one-time construction cost incurred by realignment should not exceed a prescribed threshold.

OSUB is implemented in the General Algebraic Modeling System, GAMS, [1992] and solved using the linear/integer programming solver XA [1993]. OSUB has been designed for use by an Operations Research analyst on a personal computer. GAMS has been an integral part of our modeling process by providing rapid prototyping capabilities to investigate various modeling formulations. It has also allowed us the ability to use competing solvers and solution methods. We have found XA to work best for the scenarios encountered to date. Such a scenario is shown in the next section.

3 An OSUB Application

The Army office with primary responsibility for force stationing decisions operates within the Office of the Deputy Chief of Staff for Operations (ODCSOPS). This office requested a study from the Base Realignment and Closure Office to determine the best location within the continental US for a unit consisting of two heavy brigades and a division headquarters returning from overseas. The returning unit's requirements were similar to the First Infantry Division. For this analysis, all other units were restricted to their current locations. The Army BRAC office used OSUB in this study. This is a very simple example of OSUB's capability, since only one unit's location was in question, but acceptance of OSUB-based analysis by Army decision makers is a significant milepost for the model.

The OSUB objectives were combined with weights 0.9 for the military value objective (1) and 0.1 for the cost objective (2). (The analyst therefore minimized $-0.9Z_1 + 0.1Z_2$, where the minus sign accounts for the conflicting directions of the two objectives.) Using this weighting, Fort Irwin was determined to be the optimal location, Fort Bliss was second best, followed by the other bases as shown in Figure 2. The results also indicated, by looking at objective (2)'s unweighted portion of the overall objective, that operating costs vary insignificantly. This is in strong contrast to other base closure scenarios we have analyzed, where costs vary significantly.

Figure 2 shows three groups; Forts Irwin (6,300), Bliss (6,307), and Carson(6,323) are lowest, Fort Lewis (6,600) is close, and the last group consists of the remaining eligible bases. Forts Irwin, Bliss and Carson achieved the highest ranking primarily because of the relative availability of maneuver acres. The other bases were less favorable in this regard due either to the bases' size or to the maneuver acre requirements of currently stationed units.

Prior to making a recommendation based on these results, the Army BRAC office did sensitivity analysis using OSUB. A key factor in the sensitivity analysis was the construction costs at each eligible base that would

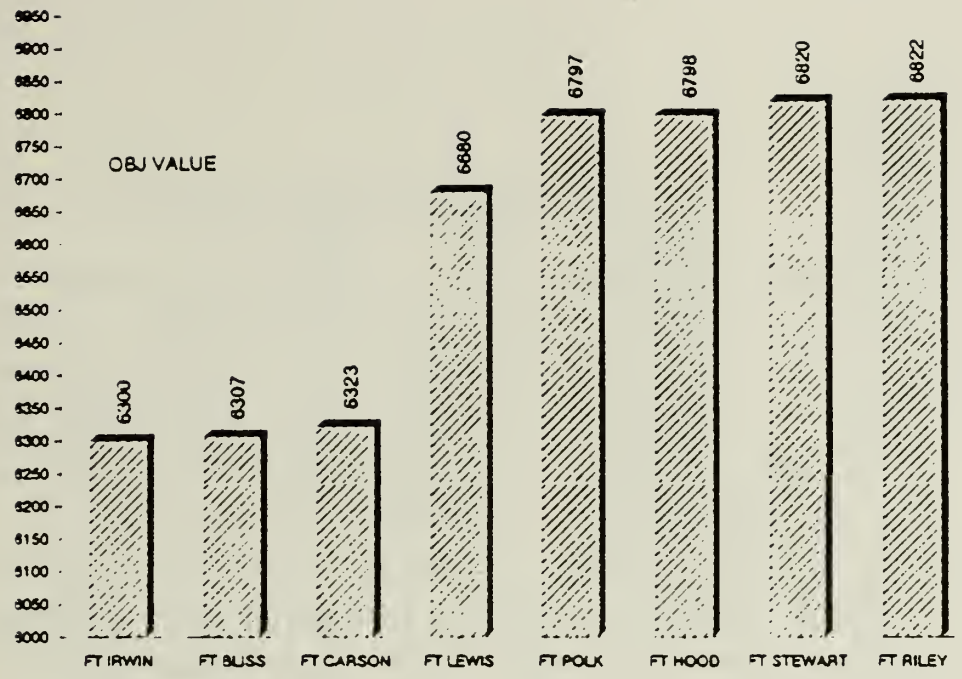

Figure 2: *Objective function values obtained for feasible locations of a unit consisting of 2 heavy brigades and a division headquarters. The original two objectives have been combined into a single minimization objective.*

be necessitated by stationing the returning units. These costs, considered by the model in Equation (9), are shown in Figure 3. Fort Lewis had the lowest construction cost by a wide margin, with Fort Bliss second. At this point, the BRAC office regarded these two bases as the most reasonable choices.

A second sensitivity analysis considered the size and composition of the returning units' effect on construction costs. The possibilities considered were: 1) the original scenario of two brigades and a division headquarters. 2) a smaller complement consisting of one brigade, and 3) a division—consisting of two heavy brigades with combat support and combat service support units. Figure 4 shows a comparison of the different construction costs under these three scenarios. Significantly, Fort Lewis was capable of accommodating one brigade within existing capacity limitations. Since construction cost and the time needed to complete construction was a factor, the BRAC office recommended Fort Lewis as the best option.

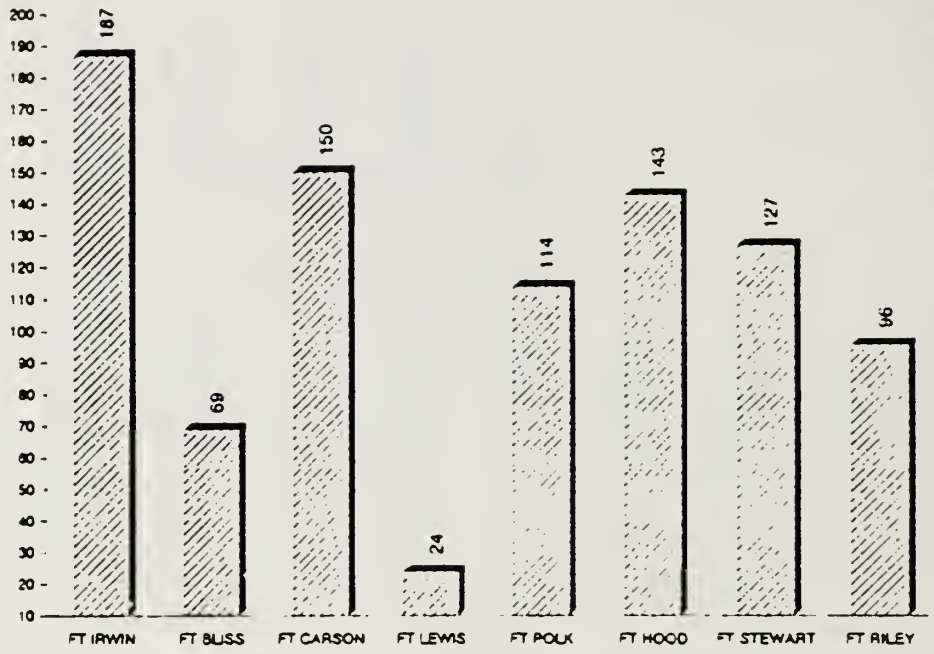

Figure 3: *Estimated military construction cost in millions of dollars for each alternative.*

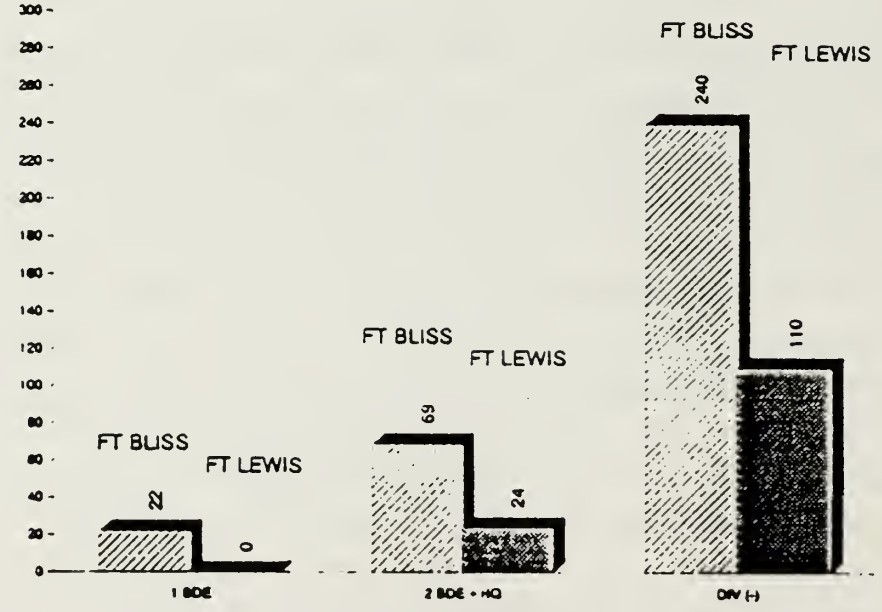

Figure 4: *Estimated military construction cost in millions of dollars for various stationing possibilities at Fort Bliss and Lewis.*

4 A Large-Scale Example

We consider an example using the bases and units previously introduced and investigate the trade-off between the military value and operating cost objectives. Due to the sensitive nature of BRAC decisions, we do not reveal the base or unit names considered in this example. The example is hypothetical and has been formed using some data that may not be realistic.

We limit the one-time construction and realignment costs to \$1.5 and \$1.0 billion respectively. We allow the model to consider the closure of 11 bases. Units, on average, can realign to approximately 15 bases. The resulting problems, after elimination of unnecessary variables and constraints, are approximately 800 equations, 300 binary variables, 900 continuous variables, and 7,500 non-zeros. For all scenarios considered in this example, the solution time is within five minutes on a 486/33 personal computer.

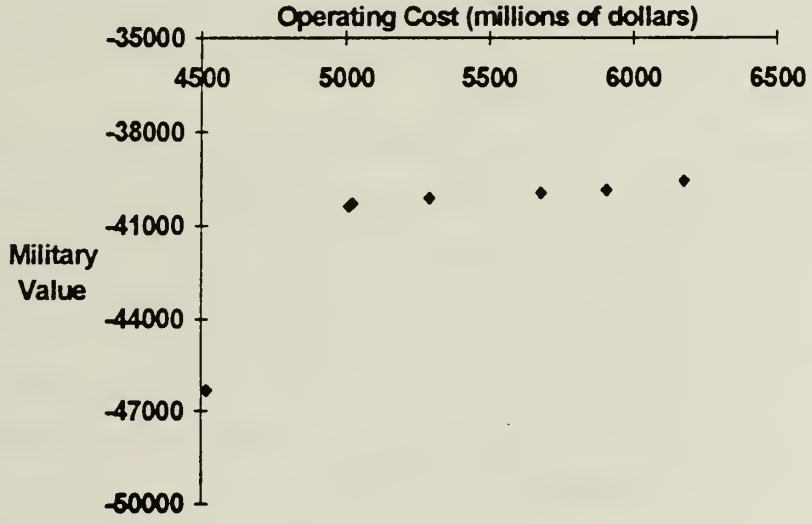

Figure 5: *Military value versus operating cost. The model seeks the maximum military value objective and minimum operating cost.*

Figure 5 shows the military value and operating cost trade-off. The values indicate a relatively minor deduction in military value of approximately 2% (-39,551 to -40,361) provides an operating cost reduction of approximately

1,000 million dollars. After this reduction however, any further closures cause significant loss of military value for only minor reductions in operating cost. A curve of this form is typically found when applying the model and provides valuable insight into both beneficial and nonbeneficial reduction.

5 Conclusions

OSUB provides a valuable tool to help analyze base realignment and closure options for maneuver and training bases. It captures a number of important factors that must be considered for any analysis: military value and operation cost objectives, constraints on maneuver acres, ranges, housing, construction, and realignment options. The user can view the effects of forcing any base to remain open, forcing any base to close, or allowing the model to decide. The user can force any unit to remain at its current location (assuming the base remains open), force it to move to a specific location, or force it to move to one of any specified subset of locations.

OSUB was used in the decision to station a unit returning from overseas at Fort Lewis, Washington. OSUB results were included in the Army's Environmental Impact Statement (Department of the Army [1993]). We have also shown in this paper that OSUB can be used from more wide-ranging analyses than this relatively simple application of the model.

The Army's base realignment and closure office's motto is "BRAC is an opportunity". OSUB helps the Army take full advantage of the opportunity. We expect the Army to use it for BRAC 1995.

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Our research has benefited and continues to benefit from exceptional Army master's students (Captain Gillman, Major Singleton, and Major Tarantino) at the Naval Postgraduate School.

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